"The Development of an Electron-focusing Method of Autoradiography under Magnification."

Thesis for the Degree of Doctor of Philosophy.

by

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INTRODUCTION.

The method of Autoradiography lacks resolution since even when good contact is achieved between the specimen containing the radioactive material and the photographic film the circle of confusion from every point of emission is so great that details less than a tenth of a millimetre are very difficult to distinguish. Several workers have improved the technique by using stripping film and melted emulsion to give good contact.

In order to increase the resolution Professor N. Feather suggested applying the electron focusing properties of a magnetic lens to the formation of the image. This method is of course limited to tracer elements which are emitters of internal conversion electrons. The chromatic aberration of the electron optical lens would be too great to give a useful image in the case of elements emitting electrons of more than one energy. It has however been found possible to use Thorium B which has a strong line, the F line, at 147.8 kev. With this source the electron beam forming the image can be considered as monokinetic since the intensity of the continuous spectrum is very low in the neighbourhood of the line.

To achieve good resolution the aperture of the lens has to be very small and this imposes another limitation on the method. This means that to obtain useful images in a reasonable exposure time very strong sources are required, particularly in the case of isotopes of short half lives. It would therefore appear that biological tracer experiments would be excluded since living organisms could not be given such large doses. The position is, however, considerably altered since electron sensitive emulsions are now available. These new emulsions enable much weaker sources to be used because each electron leaves in the emulsion a track which can be seen under a microscope. If necessary the image could be scanned, track counts being used to give the distribution of the activity in the specimen.

In addition to its application to biological tracer experiments it was thought that such an instrument would be of use in solving metallurgical and other similar problems, and so its development was put in hand.

An instrument of this type has also been developed in the United States of America by L. Marton and P.H. Abelson,[1] and they have applied the name "tracer micrography" to the method. So far as can be seen from their reports they have only used linear magnifications of 1.6 and 2 times, and attained a best resolving power of 30 microns.

The work described in this report can be divided into two main sections. Section A deals with the period prior to the delivery of the lens in mid-November 1948, and with the difficulties encountered before the final assembly about the middle of January, 1949. Section B is mainly a review of the progress made with the apparatus after its final assembly.

Section A can be conveniently divided into four sub-sections. Firstly an attempt was made to estimate the probable magnitude of the angular aperture of the permanent magnet emission lens. Secondly a design was produced for the camera and components of the vacuum system, and these were constructed in the workshop. Thirdly some time was spent in examining tracks of various types obtained in the emulsions of nuclear photographic plates. Lastly the camera, pumping line, pressure gauges and lens components were assembled and tested.

SECTION A.

I. Theoretical considerations of the optical constants of the magnetic lens.

1. Lens constants.

Glaser assumed that the field distribution along the optical axis of a magnetic lens could be given by the expression:-

$$H(z) = \frac{H_o}{1 + (\frac{z}{a})^2} \qquad \text{..........(1).}$$

where H_o is the maximum field strength at $z = 0$, and a is that coordinate where $H(z)$ drops to $H_o/2$, 2a is therefore the half width of the field curve.

From the general solution of the paraxial-ray differential equation for a magnetic field of rotational symmetry, Glaser obtained the formulae which give the focal points and principal planes of the system, and found them to be similar to those used in light optics.

The expressions he obtained for the location of the focal points F_o and F_i are:-

$$\begin{aligned} z_{F_o} &= a \cot n(\tfrac{\pi}{\omega}) \\ z_{F_i} &= -a \cot n(\tfrac{\pi}{\omega}) \end{aligned} \qquad \text{..........(2).}$$

and for the corresponding focal lengths f_o and f_i:-

$$\begin{aligned} f_o &= \frac{a}{\sin n(\frac{\pi}{\omega})} \\ f_i &= \frac{-a}{\sin n(\frac{\pi}{\omega})} \end{aligned} \qquad \text{..........(3).}$$

where $\omega = \sqrt{1 + k^2}$, is a parameter characterizing the lens strength and $k^2 = \frac{eH_o^2a^2}{8mV}$* and n is determined by the number of images formed, i.e., n = 1 when only single images are formed.

The positions of the principal points h_o, h_i are given by:-

* where e is the electronic charge, V the accelerating potential applied to the electron and all quantities in this expression are in electromagnetic units.

$$z_{ho} = a \cot \frac{\pi}{2\omega}$$
$$z_{hi} = -a \cot \frac{\pi}{2\omega} \quad ....(4).$$

For this particular lens, both Newton's lens equation:-

$$(z_o - z_{Fo})(z_i - z_{Fi}) = f_o f_i \quad ....(5).$$

and the magnification expression:-

$$M = (-1)^{n-1} \frac{f_o}{z_o - z_{Fo}} = (-1)^{n-1} \frac{z_i - z_{Fi}}{f_i} \quad ...(6).$$

apply although both object and image are within the lens. The condition for single images to exist is that:-

$$0 < \frac{eH_o^2 a^2}{8mV} < 3, \quad \text{or } 1 < \omega < 2. \quad ....(7).$$

The variation of k^2 with f, the focal length, was determined from (3) for field of half width a = 1 cm., and it was found necessary to take values of $n\pi/\omega > \pi/2$ in order to satisfy the condition (7) for single images.

2. Lens aberrations.

It is stated by Marton[2] that it is possible to determine exactly the magnitude of the lens aberrations knowing the field distribution H(z) and the paraxial-ray path r(z). Assuming that only one defect is present at a time an expression for the resolving power can be obtained.

In the case where spherical aberration is the main defect the expression given is:-

$$\delta S_p = \alpha^3 \frac{e}{96mV} \int_{+z_o}^{+z_i} \left\{ \frac{2e}{mV} H^4 + 5H'^2 - HH'' \right\} y^4 \, dz.$$

$$= \alpha^3 C_{Sp}. \qquad \text{..........(8).}$$

where $y(z)$ is that path for which $y(z_o) = 0$, and $y'(z_o) = 1$, and α is the angular aperture; δS_p being defined as the distance between two object points whose circles of confusion at the image side overlap to their centres, assuming that spherical aberration is the only defect present.

The aberration constant C_{Sp} is determined by the lens characteristics only and can be calculated as a function of the lens parameter k^2 and the object position z_o. The formula given by Marton[2] is:-

$$\frac{C_{Sp}}{a} = \frac{\pi k^2}{4(k^2+1)^{\frac{3}{2}}} \frac{(a^2 + z_o^2)^2}{a^4}$$

$$- \frac{1}{4} \frac{4k^2-3a^2+z_o^2}{4k^2+3a^2+z_F^2} \cdot \frac{z_o^2 z_F + a^2(2z_o-z_F)}{a^3} \qquad \text{.....(9).}$$

where a, k^2, z_o and z_F are as defined in section 1.

Using expressions (2) and (3) an expression for C_{Sp} can be obtained in terms of f, k^2 and a. Assuming a magnification of unity this expression becomes:-

$$C_{Sp} = af^2 \left\{ \frac{\pi k^2(2f^2 + 2f\sqrt{f^2-1}-1)}{(k^2+1)^{\frac{3}{2}}} - \frac{2k^2(\sqrt{f^2-1}+f) - a^2\left[\sqrt{f^2-1}(2f^2+1) + 2f^3\right]}{4k^2 + a^2(f^2+2)} \right\}$$

$$\text{.........(10).}$$

3. Angular aperture.

To obtain an estimate of the probable intensity of the beam forming the image, while the permanent magnet emission lens was under construction, numerical values were given to the lens constants. The numerical values chosen were based on the dimensions of the lens given in the design drawings.

For convenience the magnification was first taken as unity and the constant of spherical aberration calculated, using equations (9) and (10) for various focal lengths. The values of C_{sp} thus obtained lay between 50 and 60 cms.

Substituting these values in (8) and taking the least resolvable distance as 10 microns the corresponding angular apertures were obtained. These varied between 2.3 and 2.7 x 10^{-2} radians. Expressed as a percentage of 4π the equivalent solid angles are of the order of 0.02%.

4. Conclusions.

If the above calculations are correct the intensity of the image-forming beam would be too small to be of use with the sources suitable for biological purposes. The position however, with regard to the strength of source required, is now changed, due to the introduction of the new emulsions, which enable single electron tracks to be recorded and counted.

The examination of these plates is referred to in Section III.

In a more recent paper Marton[3] quotes Glaser's formula for the spherical aberration constant in the form:-

$$\frac{C_{Sp}}{a} = \left[\frac{\pi k^2}{4(1+k^2)^{\frac{3}{2}}} - \frac{1}{8}\,\frac{4k^2-3}{4k^2+3}\sin\frac{2\pi}{\sqrt{1+k^2}} \right] \frac{1}{\sin^4 \frac{\pi}{\sqrt{1+k^2}}} \quad (11).$$

Substituting the numerical values corresponding to the case $M = 1$, $a = 1$ cm., $n = 1$ and $f = 2$ cms. in (11) gives a value of 2.7 cms. for C_{Sp}. The corresponding angular aperture is 7.8×10^{-2} radians which is equivalent to a solid angle of 0.15% of 4π. This is over six times as great as the previous estimate.

In order to clear up this discrepancy in the results obtained for the spherical aberration constant from the two formulae (9) and (11) given by Marton, the original paper by Glaser[4] was referred to. From this paper it is clear that the expression (9) is incorrect and should be:-

$$\frac{C_{Sp}}{a} = \frac{\pi k^2}{4(k^2+1)^{\frac{3}{2}}}\,\frac{(a^2+z_0^2)^2}{a^4}$$

$$- \frac{1}{4}\,\frac{4k^2-3}{4k^2+3}\cdot\frac{a^2+z_0^2}{a^2+z_F^2}\cdot\frac{z_0^2 z_F + a^2(2z_0-z_F)}{a^3} \quad ..(12).$$

Using this expression and the same values for the focal length, half width and the parameter k^2 the value of C_{sp} obtained is now 46.4 cms. The corresponding angular aperture is thus smaller than in the previous calculation based on equation (11). It is also found however, from Glaser's paper that expression (11) applies to cases of high magnification only and therefore does not apply in the case of the emission microscope.

The variation in the angular aperture with changes in the lens has also been considered.

As the actual magnitude and shape of the field achieved in the completed lens, was not known accurately, it was not considered profitable, to pursue further, the theoretical estimates.

II. Design and construction of the lens, camera and other components.

1. The magnetic lens.

The design for the permanent magnet lens was produced by Dr. H.O.W. Richardson. (Plates I and II.) After modification of the design to minimise constructional difficulties, the manufacture of the lens was started at Telecommunications Research Establishment, Malvern in September, 1947.

The lens is composed of three axially symmetrical pole pieces, the upper and lower poles being adjustable and the middle one fixed. The magnetic circuits are completed by two rings each of eight Alnico horseshoe magnets attached by their own magnetism to the upper and middle, and middle and lower poles and prevented from slipping by the brass clamping rings. The main field is across the gap between the upper and middle poles. The lower pole piece is included in the design to enable the specimen to be placed in a region of high field to reduce the spherical aberration and increase the resolution by producing a minimum in the field distribution between the specimen and the focusing baffle.

A thumb wheel graduated in 10° intervals and provided with tommy bar holes permits the upper pole piece to be raised or lowered. Using the pitch of the thread on the sleeve carrying the upper pole piece, the width of the main field gap can be calculated in inches and converted to centimetres.

Adjustment of the lower pole piece is by means of a threaded shaft fixed into it and passing through a bush in the base plate. Part of the thread is milled away to provide a flat strip on which is engraved a millimetre scale to give the height of the pole piece above its lowest position. The position of the soft iron sleeve is also obtained from a reading on this scale.

The specimen chamber lies below the middle pole piece and can be moved along the axis on two threaded rods. Access to the specimen stage within the chamber is by way of a hole in the supporting brass cylinder and a vacuum tight door. The sylphon bellows permit the stage to be adjusted by about 1 cm. without the movement of the whole chamber. The long axial tube attached to the outer casing of the specimen chamber allows the position to be varied without destroying the vacuum seal made by the gasket just above the upper pole piece. A spring clip holds the focusing baffle tube in position after it has been pushed down into this axial tube.

The position of the specimen chamber is read by sighting across the flange on the chamber to the scale (A) engraved on the supporting cylinder; while the specimen stage position is sighted across the head of the adjusting screw on to the scale (B) engraved on the wall of the chamber plus the rotation of the screw head with respect to the sighting strip attached to the flanges. Both in the case of the vertical motion of the specimen chamber and of the vertical motion of the specimen stage within the specimen chamber, the movement with respect to the scales is achieved by the rotation of screws with heads graduated in 10^{o} intervals. Hence knowing the pitch of the screws the position can be obtained to a fraction of a millimetre and is accurately reproducible.

At its upper end the lens is terminated by the 9" diameter camera mounting plate, the central hole being large enough to give access to the gasket clamping ring which must be loosened before any adjustments can be made to the height of the specimen chamber as a whole.

2. The camera.

To obtain a record of the image of the distribution of the radioactive substance in the specimen, formed by the magnetic lens, a photographic plate is placed on the axis at a suitable distance from the lens centre. The photographic plate must be within a vacuum chamber and so a light tight, vacuum tight camera is required.

On account of the metal supply position it was decided to modify a disused ionization chamber of suitable dimensions to serve as the vacuum cylinder for the camera.

The top and bottom vacuum seals were designed to avoid relying on the original soldered joints, which were very old and dirty and therefore suspected of being unsound. The better of the two former end plates was retained as a clamping device for the new top plate, which is simply a ¼" thick brass disc with a neoprene gasket of sectional diameter 0.11" embedded in a circular groove. (Plate III.) The lower plate not only makes the vacuum seal to the camera mounting plate of the magnetic lens but serves to keep the axis of the camera in alignment with the axis of the lens, by preventing any lateral movement of the camera even when the chamber is open to the atmosphere. The $\frac{3}{8}$" thick brass base plate is screwed down on to the camera mounting plate, with the 0.275" neoprene gasket arranged in such a way as to make the seal between the base plate and the wall of the cylinder, as well as between the base plate and the camera mounting plate. (Plate III.)

To avoid loading the plate holder (Plate IV.) into the camera and fixing the cylinder lid in complete darkness, some mechanism is required for removing the light tight shutter on the plate holder after closing the cylinder. This requirement is satisfied by arranging for a system of bevel gears to be operated by the rotation of a shaft fixed to a cone union sealed into the wall of the vacuum cylinder. The gears are coupled to a pinion which engages in a rack fixed to the base of the shutter.

As it is necessary to be able to move the plate holder continuously along the axis of the cylinder in order to give a continuous variation in the image distance and hence a variation in the magnification, the plate holder is mounted on a stage which can be moved, continuously parallel to the base of the cylinder, by means of three threaded brass rods. (Plate V.)

With the dimensions used it is hoped that magnifications between 1.2 and about 20 times will be attained. Higher magnifications could conceivably be obtained by building an extension on to the cylinder.

To make the evacuation of the apparatus as rapid as possible a $2\frac{1}{4}$" hole was cut in the wall of the cylinder and a short side tube with a flange soldered into the hole.

3. The pumping line.

The flange on the camera side tube is clamped to another flange, soldered on to a length of non-magnetic Tombac flexible tubing of minimum internal diameter 2" and standard corrugations, the seal being made by a neoprene gasket of sectional diameter 0.210", internal diameter 3", retained by a suitable groove in the flange. The other end of the Tombac tubing is soldered into a brass cylinder with the end blanked off by a hard soldered brass disc. Into this cylinder, at right angles to the Tombac in the vertically downward direction, is brazed a brass side tube terminating in the cone union of the inlet to the diffusion pump.

The diffusion pump used is a type 03B two-stage Condensation Pump supplied by Metropolitan Vickers Electrical Company Limited, with Apiezon "B" oil as the working liquid. The oil is heated electrically and the pump cooled by a continuous flow of cold water. A water switch was included in the heater circuit to prevent any undue overheating of the oil in the event of an unforeseen failure in the water supply.

The low vacuum side of the diffusion pump is connected by a brass pipe through a plumber's T-piece union, adapted for use as a vacuum junction with rubber gaskets, to the backing pump. The forevacuum pump is a type D.R.1 two-stage Rotary Vacuum Pump also obtained from Metropolitan Vickers Electrical Company Limited. This pump is supplied with a combined vapour trap and oil receiver, complete with a discharge tube, air inlet valve and container for the phosphorus pentoxide or other drying agent, fitted to the inlet to the pump by means of a hand tightened union. The pump is used with the recommended Shell Rotary Vacuum Pump Oil.

The high voltage for the discharge tube is provided by an obsolete type of Rolls Royce continuously interrupted spark coil, connected to three two volt accumulators.

The other side of the T-piece union leads to the Pirani gauge and a dial gauge which gives a rough indication of the initial pumping speed. Details of the Pirani gauge and circuit are given in section IV.

III. Nuclear photographic plate observations.

To make easier the interpretation of the photographic plates which will ultimately have to be used to record the image in the study of sources of low intensity, some time was spent in examining and measuring the tracks obtained in the Kodak special nuclear plates used in other investigations in the department.

The overall lengths of alpha tracks were worked out from depth and apparent length measurements, after calibration of the scales used.

Plates exposed in a beta-ray spectrograph were examined and grain counts made on tracks of electrons of various energies. The overall lengths of the electron tracks were also calculated and plotted against energy to see if a simple length-energy relationship existed. Sufficient data was not however accumulated to establish a definite relationship.

IV. Assembly and testing of camera, pumping line, pressure gauges and lens components.

1. Camera and pumping line.

After the parts for the camera were machined in the laboratory workshop they were assembled to test the running of the gears and the opening and closing of the shutter on the plate holder. The necessary adjustments were made to the cone union, washers, spacers and couplings, until the bearings were satisfactory. To avoid having undesirable vapours within the vacuum system, flake graphite, made into a paste with Apiezon vacuum grease, was used as the lubricant for the rotating shafts.

Since all the components used in the camera and pumping line are required to be non-magnetic, to prevent any distortion of the symmetry of the field of the magnetic lens, they are mainly made of brass and so required a considerable amount of cleaning and polishing before being connected to the pumps.

A satisfactory state of cleanliness was achieved by scrubbing the surfaces with Brasso on a nylon nail brush followed by thorough washing with hot soapy water, rinsing in warm clear water and drying with hot air. Before being subjected to the above treatment soldered joints were pickled in dilute acid then rinsed and steeped in water and washing soda to get rid of flux and other chemical impurities.

The camera and each dismountable section of the pumping line was connected in turn to the two-stage rotary oil pump to test the soldered joints. The discharge tube was used to indicate the degree of vacuum obtained. Unsatisfactory joints were resoldered. Subsequently the sections were coupled together to test the gaskets, which were replaced where necessary until blackout was reached.

Before the arrival of the lens from the Telecommunications Research Establishment, Malvern in mid-November, 1948, a Pirani gauge was constructed and included in the pumping line to indicate the pressure reached by the two-stage rotary pump. The pumping line was completed, assembled and the two-stage Apiezon oil diffusion pump tested.

The rate of flow of the water through the cooling jacket of the diffusion pump was varied until the optimum conditions of operation of the pump were determined. Best performance was obtained with a water flow of approximately 1 pint per minute at an initial temperature of about 15°C.

When the vacuum was sufficiently good a short side tube was soldered into the wall of the camera vacuum cylinder near its upper end. An ionization gauge was waxed into this tube to serve as the pressure indicator for the high vacuum side of the system.

2. The Pirani gauge.

The gauge consists of two electric light bulbs of an obsolete type, one evacuated and sealed off at a very low pressure, the other with an extension tube connected into the vacuum system. The use of the sealed bulb should make the gauge insensitive to changes in room temperature, but to avoid any possible interference caused by temperature fluctuations in the surrounding air the bulbs are kept side by side in a cotton wool filled aluminium box.

The filaments of the bulbs, which have a high coefficient of electrical resistance, are heated by a constant current and are connected, with suitable known fixed and variable resistances, in a Wheatstone bridge arrangement. (Plate VI.) The bridge is balanced when the pressures in the two bulbs are equal. When the pressures are not the same, the pressure in the system is measured in terms of the additional resistance required to restore the balance of the bridge.

The gauge is switched on after blackout in the discharge tube is reached and is used until the pressure on the high vacuum side is of the order of 10^{-4} mm. of mercury, when the ionization gauge can be switched on.

3. The ionization gauge.

This gauge consists of a triode, manufactured for use as an ionization gauge, arranged in a suitable circuit (Plate VI.) with a sensitive microammeter to measure the plate current. The ratio of the plate current to the grid current is proportional to the pressure at pressures below about 10^{-4} mm. mercury; and since 1μamp. plate current at 1 milliamp. grid current is equivalent to a pressure of 10^{-4} mm. mercury, the pressure in the system can be obtained from this ratio.

4. The lens assembly.

After mounting the apparatus in position on the prepared bench, (Plate VII.) the specimen chamber and the connecting tubes were tested under vacuum. These were not satisfactory since the gaskets and soldered joints were imperfect. Since the assembly of the lens takes place working from the top to the base, the instrument was completely dismantled and each component tested separately until the leaks were located.

The leaks were patched and the gaskets replaced. Starting with the Tombac tubing, first alone then in conjunction with each other section in turn, pumping was continued with both pumps running until finally the pressure attained, as given by the ionization gauge (temporarily transferred from the camera to a convenient place in the pumping line) became independent of the volume being evacuated. After pumping for five or six hours the pressure in each case dropped to about 2×10^{-5} mm. mercury.

The sections were then combined and evacuated, adjustments being made to the joints until the pressure was again in the neighbourhood of 3×10^{-5} mm. mercury.

The specimen chamber, magnets and camera were reassembled along with the remaining parts of the instrument and were still found satisfactory under vacuum.

SECTION B.

I. The operation of the instrument.

1. Magnetization of the pole pieces of the lens.

The resistances of the lens coils were measured. The upper coil has a resistance of 3.25 ohms and the lower coil 1.25 ohms.

In order to pass the necessary high flux during magnetization the upper pole piece was lowered to bring the upper and middle pole pieces into as close contact as possible. The lower pole piece and soft iron sleeve were raised until in contact with the underside of the specimen stage. The roof of the specimen chamber was strengthened with a piece of cobalt steel placed between the roof and floor of the chamber, the specimen chamber being in its highest possible position.

An external resistance of 5.4 ohms (20 amps. max.) was included in the circuit, making a total resistance of approximately 10 ohms since the coils were connected in series. As the D.C. mains supply 230 volts a magnetizing current of approximately 23 amps., the maximum obtainable with the available resistance, was passed.

2. Preliminary experiments.

The tube to carry the focusing annulus, the centering spider and the mark I baffle were machined, (Plate VIII.) and the combination pushed down into a position in the inner tube above the specimen stage slightly higher than the upper pole piece level, on the axis of the lens.

The position of the specimen table, given by the reading on the scale on the brass cylinder (Scale A.) and on the scale on the specimen chamber wall (Scale B.), was noted. The main field gap was first set at 0.64 cms. i.e., about 1/5 of the maximum possible distance. The setting of the height of the lower pole piece at magnetization was left for the first two exposures.

Ilford nuclear plate type B 2, with 50μ thick emulsion, was selected for the first test, cut to shape and loaded into the plate holder. A position about half way up the camera cylinder was chosen for the plate.

Object No. 1 was made by soldering a 1.3 cm. perforated disc to the shaft of an 8 BA brass screw. (Detailed drawings of source buttons are shown in Plates XI and XII.) As it was desired to make use of thorium B with its strong F line at 147.8 kev. as a source of nearly monokinetic electrons, this object was activated in a weak radiothorium pot for a period of 22 hours. Since thoron has a short half life a convenient way of obtaining a layer of thorium active deposit on a metal surface and therefore a source of thorium B is to expose it in a vessel containing an "emanating" source of radiothorium. This consists of a highly porous precipitate of ferric hydroxide containing radiothorium, which is the parent of thoron. It is contained in a small metal vessel, preferably of stainless steel, and the metal surface to be activated is exposed in the gas phase. The button is screwed into a brass rod passing through an ebonite plug which closes the vessel to prevent the thoron from escaping, and is kept either negative or positive with respect to the vessel depending on the voltage used. An earthed disc prevents collection on the front face of the ebonite plug.

On removal the button was transferred to the source holder which, before the modification referred to later, was a thin brass slide with locating pips on the underside to fit into the groove provided in the specimen stage, having an 8 BA tapped hole drilled in the position calculated from the drawings to be on the axis of the lens.

The source holder was slipped into place in the specimen chamber and the door replaced after greasing. The top plate of the camera was fixed in position and the pumps switched on. After pumping for an hour the shutter was removed from the plate holder and the exposure commenced. Three and a quarter hours later the shutter was closed and the ionization gauge and the diffusion pump switched off. The oil in the diffusion pump was given an hour to cool before the backing pump was cut off.

On removal from the holder the plate was found to be broken in three and the emulsion was peeling off around the edges. Processing was carried out as recommended, an unexposed piece taken from the original plate being done at the same time as a control. Examination of the exposed plate under the microscope showed considerable darkening and numerous alpha tracks. The unexposed plate showed no appreciable darkening and no tracks.

Plates were tested in the holder and under vacuum for various periods without sources being present. Ilford type C 2, 100μ emulsions were found to stand up to the procedure better than the thinner B 2 emulsions, and were therefore used for the second exposure which was a repeat of the first but with a plain 8 BA screw as source button No. 2. The exposure time was four and a half hours and the plate was again broken and peeling with no visible blackening.

Suspecting that the source strengths were too weak button No. 3, a modified 8 BA screw was activated on a stronger radiothorium pot. The inside structure of the camera was removed and a wire frame put in its place to enable 4 plates to be exposed simultaneously at heights of 4,9,14 and 19 cms. above the camera mounting plate, each one arranged to cover only $\frac{1}{4}$ of the image area.

The camera mounting plate level was selected as a suitable zero point for measurements down inside the tube and up into the camera, and all subsequent measurements in the vertical direction on the image side of the lens, will be quoted with reference to this zero.

The plates on the lower stages of the frame had a definite area of blackening with a circular boundary after over 7 hours exposure. To try to reduce the blackening due to alpha and gamma rays which accompany the beta rays from the thorium active deposit, a headless 8 BA screw was next used as source No. 4. The plate Ilford type C 2 again peeled badly but a circular blackened area with a shadow of the central stop could be distinguished.

It was obvious at this point that a more reliable type of plate would have to be found and after trying several types of plate double coated X-ray film was found to behave satisfactorily under the conditions in the vacuum chamber, and development and fixing is much more rapid than is the case with nuclear emulsions, which is an additional advantage.

Even smaller objects were considered desirable and to facilitate handling them when radioactive the ebonite plug, used to support the button during activation in the radiothorium pot, was redesigned. A 5 BA screw was cut to a length of 4.5 mm. drilled in for about 2 mm. from one end the other end turned down to 1 mm. diameter for a length of about 2 mm. (No. 5.) A brass rod with tip turned down to be a sliding fit into the hole in the screw has a terminal at its other end. This rod is pushed along the axis of the ebonite plug until the 1 mm. tip of the source button projects from a small hole cut in the lower side of the plug. After activation the rod is withdrawn and the source screwed into the source holder from the underside without spoiling the distribution of the active deposit on its surface.

Using this source button, and a similar one No. 6, activated for various periods, a number of exposures were made but no useful results were obtained in these first few experiments. The positions of the specimen chamber, pole pieces and focusing baffle were altered but very little improvement in the image was obtained.

The focusing baffle was withdrawn and attempts were made to measure the field in the tube along the axis. Fluxmeter search coils were wound on small bobbins withdifferentnumbers of turns. Up to 90 turns of 0.038 cm. lacquered wire were used wound in four layers on a core of 1 cm. diameter giving a mean radius of 0.58 cm. Deflections on the fluxmeter were negligible in the main field gap, so it was decided to pass a higher magnetizing current through the upper coil only.

3. Remagnetization of the upper circuit.

The lower pole piece and sleeve were withdrawn to their lowest position. The upper pole piece was moved until the gap between the upper and middle pole piece was 6.4 mm. The upper coil was connected to the D.C. mains in a circuit with suitable variable resistances and a 50 ampere meter. (Plate IX.)

A search coil was attached to an adjustable rod enabling it to be placed at the centre of the gap between the pole pieces to measure the fields corresponding to the various currents which were passed. The coil was connected to a fluxmeter with a scale graduated in 100 divisions where each division corresponds to 10,000 Maxwell turns.

Resistance R_1 was adjusted to make the total resistance in the circuit 38.3 ohms thus giving a current of 6 amps. on switching on when a fluxmeter deflection of 9.5 divisions was produced. R_1 was then removed reducing the total resistance to 11.5 ohms and increasing the current to 20 amps. and the fluxmeter deflection to 15 divisions. Next R_3 was cut out giving a total resistance of 6.5 ohms, a current of 35 amps. and a fluxmeter deflection increase of 9 divisions. Finally R_2 was cut out for a second or two. The final current was of the order of 49 amps.

The gap between the pole pieces was reduced to 3.2 mm. and a fluxmeter deflection of 12.5 divisions was produced on withdrawing the coil. Reducing the gap still further to 1.6 mm. and readjusting the search coil to be at the centre of the gap the resistances were again cut out and the maximum current of 49 amps. passed momentarily.

After the circuit was disconnected the fluxmeter coil was set at various positions in the tube and the position giving maximum deflection found. This maximum deflection of 13 divisions corresponds to a maximum field of approximately 1280 oersteds. As only an indication of the order of magnitude of the field was required, the fluxmeter was not calibrated accurately with its coil in known fields.

From this maximum field position the depth of the lower end of the upper pole piece below the camera mounting plate was estimated and compared with the distance given by the design drawings. The focusing baffle tube was reinserted to make the base of the baffle approximately level with the lower end of the upper pole piece.

4. Tests with various object types.

With object No. 6 as the source plates were exposed at various levels in the camera. A central beam was clearly indicated by a very diffuse image.

The changes in the maximum field strength produced by altering the width of the gap between the upper and middle pole pieces were examined. When the upper pole piece reached its upper limit the maximum field was only about 1080 oersteds. With the gap at 1.7 cm. plates were exposed in turn at three very different levels without moving or reactivating object No. 5 between the exposures. Since the actual object and image distances cannot be measured directly the image distances are measured in terms of the height of the photographic plate above the camera mounting plate. By measuring the diameters of the images obtained at the three levels, (Plate XIII a,b,c.) the ratios of the magnifications were calculated. Since the object distance was constant these enabled the positions of the principal planes of the electron optical system to be determined. From the positions of the principal planes the actual object and image distances were calculated.

The field gap was again increased to 2.35 cms. by raising the upper pole piece and the magnifications of the images (Plate XIII d,e.) were found to be reduced by the amount expected, assuming that the principal planes are crossed and coincide approximately with the positions of the limits of the pole pieces.

To obtain a better object (No. 7.) a 5 BA screw was drilled through the centre and a pair of 0.1mm. platinum wires were soldered across the hole. Only one of the wires however became properly active and the image was difficult to measure. Further objects (of type No. 8.) were made from 0.05mm platinum wire, but these were too easily distorted and broken.

A piece of wire gauze was mounted on No. 1 after drilling away most of its surface to make a source (No. 9.) with fine detail. The central parts of this object did not become sufficiently active to give images. The thin brass ring (No.10.) left after a screw had been turned down and drilled through the centre was also tried but the active deposit was not uniformly distributed on the metal surface.

To examine the distribution of activity on the objects, contact radioautographs were made at suitable intervals after activation. The autographs made with extremely short exposure times of the buttons to the photographic film showed clearly that the active deposit was far from uniformly distributed on the surface of the button. (Plate XIV a,b.) In the case of objects of diameter greater than 2 mm. the portion of the surface in the centre of the button, and therefore the region about the axis of the lens, showed very little activity. This accounts for the lack of blackening with the larger objects.

A return was made to small solid object buttons which were machined, polished and then cut to some pattern. The first of this type was a 0.9 mm. brass button with cuts made by the blade of a penknife. (No. 5 modified.) Images of this source showed the cuts as areas of low activity, the ridge between two adjacent cuts being strongly active. (Plate XIV c,d.)

To try to improve on this type of source a button was engraved in a dividing machine. The machine has a screw with a pitch of 1 mm. and a control wheel divided into 400 divisions making it possible to move the cutting tool in steps of 1/400 mm. or 2.5 microns. A pattern of 28 lines with spacings from 10 to 150 microns was engraved across the face of the 2.35 mm. diameter button. (No. 11.) The grooves on this button were very shallow and the image was not satisfactory. (Plate XIV e.) An attempt was made to clear out the grooves after activation of the button, but this was found to be very difficult on account of the layer of oxide produced while in the radiothorium pot.

Close examination of the highly active object, to facilitate the scraping out of the grooves, was not possible. Plate XIV f. shows the image obtained with the modified source.

More satisfactory objects (Nos. 12 and 13.) were obtained by engraving much deeper and broader lines. These did not require clearing out after activation since the contrast in the image was sufficiently good without doing so. (Plate XV a,b.)

At this point it was considered desirable to have a rough idea of the efficiency of collection of active deposit by the buttons to make the estimation of exposure times more accurate. For this purpose a gold leaf electroscope was mounted in a stand giving a readily reproducible geometry when measuring the strength of the sources. The source, mounted in the holder, was placed each time in a standard position in a box and the time of collapse of the leaf noted, for the fall through the same forty divisions. To make the rate of fall conveniently slow when the source was strong lead foils were placed in front of the electroscope window.

By making allowance for the relative surface areas of the various buttons, exposure times could be estimated to within about 20%. The different types of double coated X-ray film which have been used were found to require approximately the same exposure time under the same conditions of pressure etc., and the processing times are more or less standard.

From the shape of the "circular" patch of blackening caused by the alpha rays which manage to pass through the aperture it was clear that the object was not on the axis of symmetry of the lens. To permit the more accurate alignment of the optical system the source holder had to be modified. (Plate X.) A section of the upper surface of the holder in the neighbourhood of the axial position was milled away. A thin strip of brass with a 5 BA tapped hole was made to slide into this section. The slide can be clamped in any desired position by means of a screw passing through a slot in the slide into a tapped hole in the body of the holder. A line was engraved across the slide and on to the holder to give a zero point for measurement of the distance moved by the slide during adjustments. The distance between the two halves of the line is measured with a microscope and is called positive or negative according to whether or not the line on the slide is nearer the axis than the line on the holder.

Adjustments in the direction at right angles to the above were made possible by milling away a few millimetres off the end which made contact with the stop on the specimen stage then making up the distance with a small screw fixed firmly into a tapped hole in the end. By increasing or reducing the length of screw projecting from the hole the distance from the stop can be increased or reduced. Finally a slot was milled in the holder long enough to allow the source to be loaded into the slide from the underside at any position.

A series of exposures was taken with object No. 13 until the centering was satisfactory, the final distances being measured and noted.

The next set of experiments aimed at improving the quality of the images by reducing the dimensions in the objects. Two pairs of intersecting lines, the first pair in the form of a V (No. 14.) and the second a X(No. 15.) gave sharp images. (Plate XV c,d.) Three intersecting 0.002" silver covered platinum wires mounted on a screw were shielded with mica (No. 16.) except for the central region and exposed in the radiothorium pot. Activation of this button was poor and the image disappointing. It was later discovered however that the dish containing the radiothorium had been upset making the strong source pot unserviceable for several months.

To increase the resolution of the instrument the aperture of the focusing baffle was reduced to just under half its size. (Plate VIII Mark II.) After replacing the focusing tube with the new mark II baffle in the same position as before object No. 15 was used for comparison with previous exposures. Strong sources were not however available and it is difficult to compare these weak source images (Plate XV e,f.) with those obtained with the strong sources, since the intensities of the backgrounds in the two cases are very different.

One further attempt was made to make an object with fine detail. Object No. 5 was polished once more and three holes were drilled into the face with a 0.1 mm. drill. (No. 17.) (Plate XVI a.)

5. Naturally occuring specimens.

A search was made for suitable materials with holes of different sizes. Pieces of porous pot, plaster, pumice stone and tile were polished flat and examined under a microscope. Pumice stone was found to be easily ground into thin slices and was selected for the first object. The mounting of the sections for activation presented the first difficulty since the cement used had to stand up to exposure to the chemical action in the radiothorium pot as well as to the outgassing in the vacuum chamber.

Cements of the irreversible type were used to attach test pieces of pumice stone to slabs of brass. The most successful types were made from sodium silicate and magnesium oxide moistened with water and from sodium silicate with dry french chalk. To avoid having to alter the specimen holder attempts were made to mount discs of pumice stone approximately 3 mm. diameter on pieces of 5 BA screw with the magnesium oxide water glass cement. After 24 hours hardening three of the specimens seemed satisfactory and one was carefully coated with colloidal graphite to render it conducting. Microscopic examination of the specimen after coating comfirmed that a layer of graphite could be applied without spoiling the porosity of the stone. (No. 18.)

Activation was continued for about 35 hours in the hope of collecting as much activity as possible. The total activity on the button was about half that of the previous buttons but because of the much larger area the images were underexposed although some holes round the circumference could be distinguished. Contact autoradiographs (Plate XVI b.) made with this button showed the same features as the non contact images, namely that the centre of the object had not collected an effective amount of the activity. This had also been found in the case of metal objects of similar dimensions.

The second source of this type gave even poorer results. After being activated once, these objects came apart as the cement left the brass surface. "Porcenam" enamel and black wax were tried as cements.

The "Porcenam" did not dry out properly under the pumice stone and the black wax, although strong enough at first, became brittle and cracked when handled in preparation for activation. To get round the difficulty a chemical method of depositing the thorium B on to the pumice stone was adopted.

Platinum wire 0.3 mm. diameter was bent into two loops at one end, threaded through a portion of 5 BA screw which had been drilled with a 53 drill to very near the end and through the end with a 0.35 mm. drill. The wire passed out through another 0.35 mm. hole drilled through the base of a notch in the side of the screw and then was fastened by winding round in the notch in such a way as to make easy the removal of the active wire with tweezers. (No. 24. Plate XII.)

On removal from the radiothorium pot the wire was unwound and placed in a quartz crucible. A drop of concentrated hydrochloric acid was allowed to fall on the active tip to dissolve off the thorium active deposit from the platinum. After evaporation to dryness with gentle heating it was redissolved in dilute hydrochloric acid. Hydrogen sulphide was bubbled into the acid in the crucible until a brownish colouring appeared, due to the precipitation of the sulphide. The resulting liquid was dropped on to the surface of a thin slice of pumice stone.

Nothing useful was obtained with this source even after repeating the process several times. Contact autoradiographs (Plate XVI c,d.) showed quite a good distribution of activity over the surface but the strength of the active layer was rather low for non-contact exposures.

Bones from various animals were boiled, dried and cut into slices with a hacksaw. After examination the sections likely to be of use were put into an oven to become thoroughly dry and hard, to enable the bones to be filed to the required shape. The head of a rabbit's long bone was found to be the easiest to file down to a little peg with the top about 3 mm. wide. While very hot and dry the peg was pushed into a 57 drill hole in the 2 mm. tip of a modified 5 BA screw filled with molten black wax. When cool the object was brushed lightly with colloidal graphite and activated. The bone structure was clearly visible particularly round the outside where the collection of deposit is good. (Plate XVI e.) An autoradiograph of another source of this type is shown in Plate XVI f.

As an alternative to colloidal graphite some sections were thinly coated with aluminium in an evaporation apparatus but these were not satisfactory.

6. Objects made from electron microscope grids.

A gift of a few electron microscope specimen support grids was received. These are copper rings of outer diameter 3 mm., inner diameter 2.3 mm. with a mesh of copper bars across the central hole. The bars appear to be generally about 30 microns thick but in some cases are as much as 55 microns. The gaps between the bars also vary between 80 microns and 55 microns. The first source made from the grids was simply a piece of 5 BA screw with the grid soldered on to the face. (No. 19.) The copper ring was visible in the images but there was no sign of the individual wires. As previously mentioned, objects of diameter greater then about 1.2 mm. have never been found to become uniformly active, so attempts were made to solder a small piece of the mesh on to the tip of a screw turned down to 1 mm. Some of the holes were spoilt by solder but sufficient were still clear to make it worth while using it as a specimen. (No. 20.)

The object distance was varied in steps of 1 mm. until the structure began to appear and then in steps of 1/6 mm. until the best position was found. Some of the results of exposures taken in this series are shown in Plate XVII. Unfortunately before being able to show that the best position had indeed been reached the grid was almost completely destroyed by the continual exposure to the bombardment by radiation and chemical action in the radiothorium pot. In the last few exposures with this source the activity was mainly concentrated in a few spots. When the decay of the active deposit on the button was complete the grid was examined under a microscope and these bright spots were found to correspond to the regions in which a loose end of the broken mesh stuck up above the surface of the button making irregularities in the field distribution when a charge was put on the button during activation.

The tests to find the best object position were continued after a similar source button had been made up. When this position was found the effect of altering the position of the focusing baffle was examined. Starting 1 cm. above the original position the baffle was moved in steps of 1 mm. for 1.7 cms. Improvement in the image was seen for the first 9 mm. movement and after 11 mm. a definite deterioration took place showing that the original position was satisfactory. (Plates XVIII and XIX.)

7. Aperture variations.

Since the spherical aberration in a lens system increases with increasing distance of the electron paths from the optical axis of the system some improvement in the quality of the image might be expected if the central rays were used instead of the beam passing through an aperture with a central stop. To see if any improvement could be achieved in this manner a new baffle was made with an axial hole instead of an annulus. (Plate VIII Mark III.) The area of the hole was the same as the area of the annulus to give the same intensity in the image after a known time. The blackening in the negative in the region of the image is however much increased in this case by the presence of the alpha rays from the ThC and ThC' which can now pass straight through along the axis. With the same positions as in the previous best exposure the image was fuzzy but part of the grid was distinguishable in spite of the background. (Plate XX a.)

Two further baffles of this type Mark IV and V were tried and considerable improvement was obtained with the smallest (1/16" diameter.) baffle hole. (Plate XX b,c.) Slight adjustment was necessary in the object distance to get sharp focusing but it was difficult to judge the sharpness since in successive exposures (Plate XX d,e.) the grid again showed signs of movement with respect to the tip of the button and very soon disintegrated completely. To replace this button one was made with a previously tinned piece of grid.

Sheets of cellophane and aluminium foils were placed immediately before the photographic film to reduce the alpha ray background. Since the ThC' alphas have a range in air of 8.5 cms. they would require about 13 mg/cm^2 aluminium to filter them out. Long before this thickness is reached the beta rays forming the image are affected with the result that a deterioration instead of an improvement is obtained.

The variation in the spherical aberration with distance from the axis was re-examined with a view to making another annular focusing baffle of most favourable inner radius. The conclusion reached was that for small areas the area of an annulus of inner radius r and width dr is approximately $2\pi rdr$, so for constant areas of annuli dr is proportional to $1/r$. The aberration x measured along the axis is proportional to r^2 and therefore $dx = 2rdr = 2r1/r$ = constant, i.e., for equal small areas the aberration is approximately constant and so it was not necessary to make a new central stop of smaller radius. The inner diameter of the outer baffle was reduced to 9/32" making the area of the gap approximately 0.06 sq. cms. The solid angle of collection with an object 6.3 cms. below the baffle is of the order of 0.01% of 4π.

Although exposure times have had to be increased considerably with this Mark VI baffle the quality of the images obtained has been very much better.

8. Estimation of resolving power and final focusing experiments.

To make an estimate of the resolution attainable with the Mark VI aperture a button (No. 23.) was engraved with a pattern of fine lines. The widths of the grooves and the distances between them were measured in terms of the calibrated eyepiece scale of a microscope. These widths ranged from 12 to 50 microns and the spaces between the lines from 19 to 175 microns. Although the diameter of the button was only 1 mm. the activity was more uniformly distributed on one side than on the other and all nine lines do not appear in the image. (Plate XXI a.) The magnification in this case is approximately 7 times and part of the 12 micron groove is just visible.

A curved burr made by the cutting tool during the facing off of the screw in the lathe can be identified as a region of high activity. The black pitted areas which can be clearly seen in Plate XXI (b) indicate the deterioration in the surface of the button as a result of only three periods of activation in the radiothorium pot.

Since detail of the order of 12 microns is difficult to see even when magnified 7 times the electron image was enlarged optically about 6 times to give an image with a total magnification of approximately 42 times. (Plate XXI c.) Although the grain size of the no-screen X-ray film is fairly large, detail is still quite sharp at this magnification.

A second pattern with lines crossing at an angle of approximately 37° was engraved on a 1.14 mm. diameter button. (No. 25.) The grooves in this case are from 20 to 50 microns wide. The resolution in the image of this button (Plate XXII a.) is better than 10 microns. At a magnification of 42 times (Plate XXII b.) 1 mm. in the image is equivalent to approximately 24 microns in the object.

As the measurement of all the dimensions in the object under the microscope is rather tedious, advantage was taken of an opportunity to use a Vickers Projection Microscope for a short time. This instrument is normally used as a high magnification transmission microscope and with the accessories available it was difficult to reduce the magnification sufficiently to take in the whole of the button surface at once. A minimum magnification of 42 times was achieved by removing the projection lens, but the images were partially spoilt by scattered light from the reflecting mirror. Object No. 25 was unfortunately only photographed in this way some time after it had been used as a source when the reflecting power of the metal was considerably reduced and the edges of the cuts slightly eroded. (Plate XXII c.)

The effect of introducing the lower pole piece was again tried but certainly no improvement in the image was attained. This pole piece will require to be remagnetized and tried at numerous positions before a decision as to its usefulness can be reached.

The final source button of mean diameter 0.83 mm.

was photographed in the Projection Microscope at a magnification of 42 times immediately after being engraved. Several grooves as narrow as 5 and 6 microns were achieved in this pattern but they do not all show clearly in the print, (Plate XXIII a.) the lines in one direction being more favourably illuminated than those in the other. In the electron image (Plate XXIII b.) with a magnification of 7 times these grooves can be seen, showing that the resolution is better than 5 or 6 microns.

With the fine grain electron sensitive emulsions, (Plates XXIII c to f.) the resolution is seen to be even better when measurements are made on the image under a low power microscope. The only electron sensitive plates immediately available at the time when these final experiments were being done were some six-months old pieces of Kodak N.T. 2a, 100μ plates. These had a fairly high background fog but even so the images are very sharp.

To see how great a reduction in source strength is possible when such plates are used four exposures were made with the same source without reactivating in between. The first exposure of 2 hours' duration (Plate XXIII c.) was with the button shown in Plate XXIII (a) commencing 20 minutes after its removal from the radiothorium pot at the end of 22½ hours' activation. With the types of plate previously used and with the Mark VI baffle this exposure would have been too short to give a useful image. The second exposure (Plate XXIII d.) was started $2\frac{1}{2}$ hours after removal from the pot and was continued for 16 hours. This is only slightly longer than the exposure required under favourable conditions with the no-screen X-ray film. The third exposure, (Plate XXIII e.) begun when the source was 19 hours 10 minutes old, lasted for 23 hours; while the fourth (Plate XXIII f.) was prolonged for 47 hours, 43 hours 40 minutes after activation.

Since the half life of thorium B is 10.6 hours the fraction of the initial activity contributing to each image can be calculated approximately. These are respectively 0.14, 0.54, 0.24 and 0.06. This means that sources about a tenth of the strength formerly required can easily be used. Now that a fresh batch of beta-plates has been received experiments will be carried out to see how accurately the distribution of activity can be mapped out when the source is too weak to give an image visible to the unaided eye.

II. Possible applications of the instrument.

1. In Metallurgy.

Where radioactive tracers are being used to study metallic diffusion and other allied problems this method may prove useful if any of the isotopes used have suitable radiation characteristics, or participate in any of the reactions being investigated. The properties of some alloys appear to depend on slight impurities whose position with respect to the constituent metal crystals is not certain. If suitable isotopes of these impurities can be obtained the emission electron microscope may be able to show where these elements go, since if the dimensions of the metallic crystals are large enough the boundaries of the crystals should be identifiable.

Small pieces of soft alloys are being relief polished to see if their structure can be resolved when they are activated in the same manner as the engraved source buttons. This will give some indication of the lower limit in the structural size of the metals which could be used.

2. In Biological tracer experiments.

A list has been made of isotopes having internal conversion electrons and it is hoped to be able to select from it some isotopes which have suitable half lives and beta energies which are of interest in the biological field. Meantime experiments are in hand to investigate the distribution of lead (Th.B.) in the organs of the rabbit. It is intended to try to compare the results obtained with this method with those already obtained by other tracer techniques. It has been estimated that sufficient activity should be present in the liver of the rabbit 1 hour after administration by injection of a few millicuries of Th.B to give some sort of image from a thin slice of the tissue, but this may not be the case.

If a long half life isotope were available the exposure could presumably be extended until the activity collected was sufficient, provided of course that the tissue specimen could be made to stand up to the conditions in the vacuum chamber.

SUMMARY.

The resolution in the method of Autoradiography has been increased by applying the electron focusing properties of a magnetic lens to the formation of the image. Using the F line of Thorium B at 147.8 kev. as the monokinetic electron source images have been obtained of patterns engraved on the surfaces of brass buttons. A resolution better than 5 microns has been reached when the aperture of the permanent magnet lens assembly was of the order of 0.01% of 4π. The best results were obtained when the image was recorded on Kodak NT 2a electron sensitive nuclear emulsions.

Experiments with pumice stone and bone sections are also described but these were not so satisfactory as the metal specimens. The method is now being applied to examine the distribution of lead in the organs of the rabbit.

BIBLIOGRAPHY.

1. L. Marton and P.H. Abelson. Science Vol. 106, No. 2742, July 18, 1947.
2. L. Marton and R.G.E. Hutter. Proc. I.R.E. Vol. 32, No.9, September 1944.
3. L. Marton. Reports on Progress in Physics. Vol. X, p. 204, 1946.
4. W. Glaser. Zeit. für Phys. Vol. 117, pp. 285-315, 1941.

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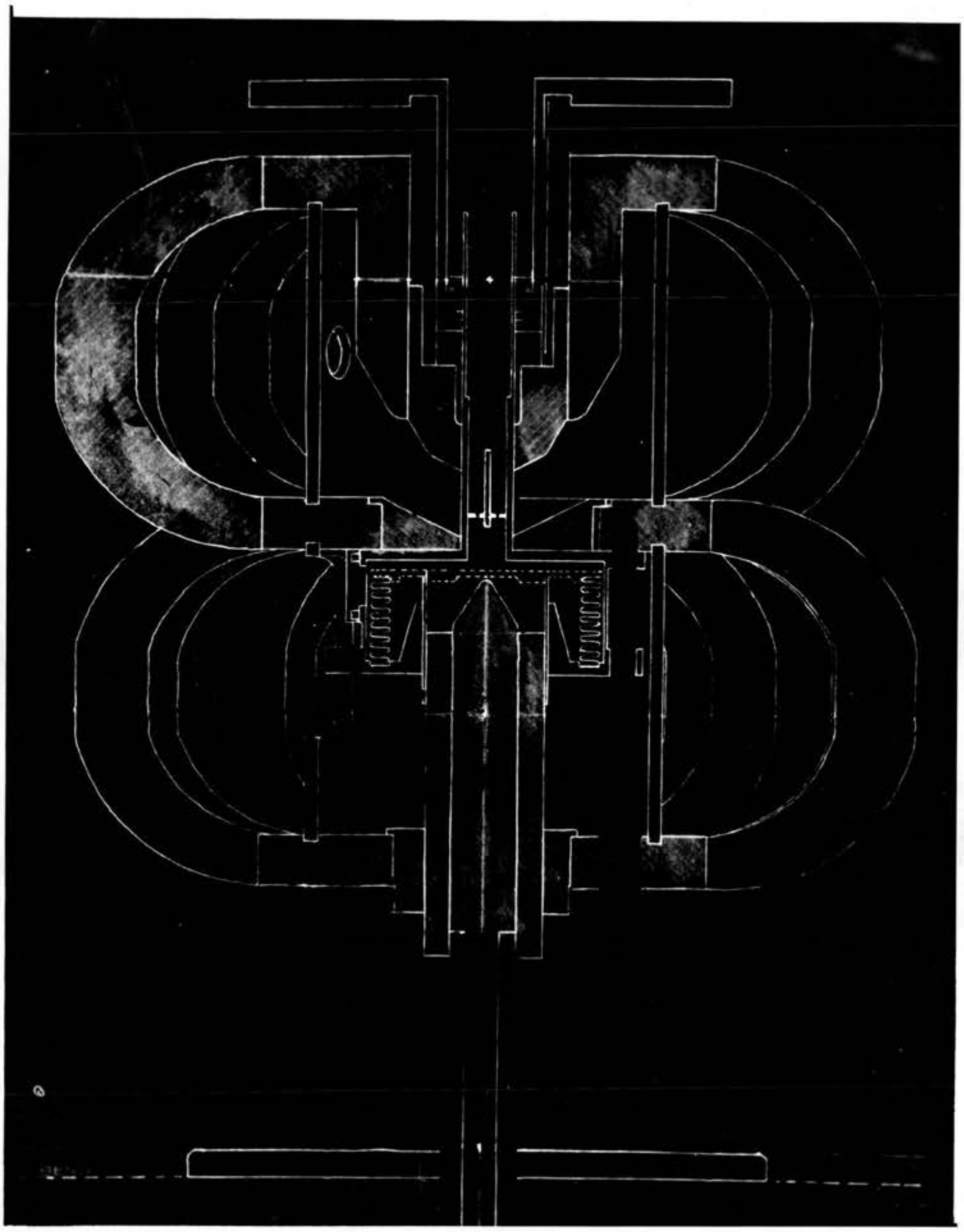


Plate I.

The Magnetic Lens Section Showing Pole Pieces.

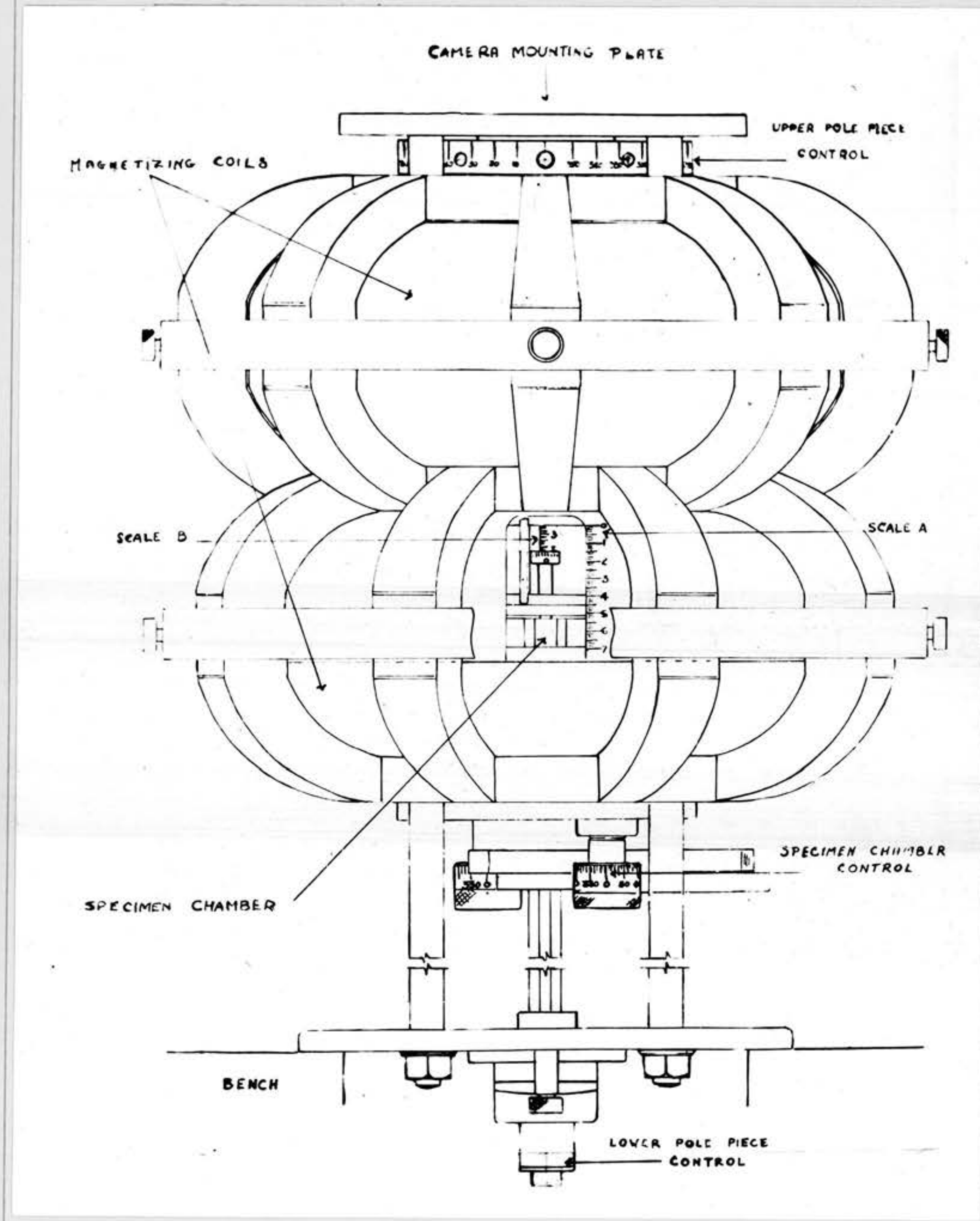
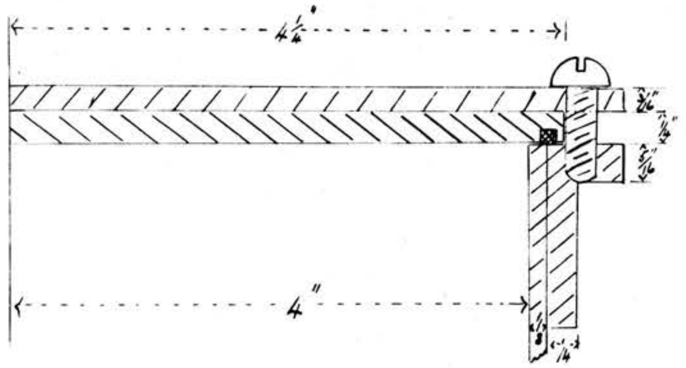
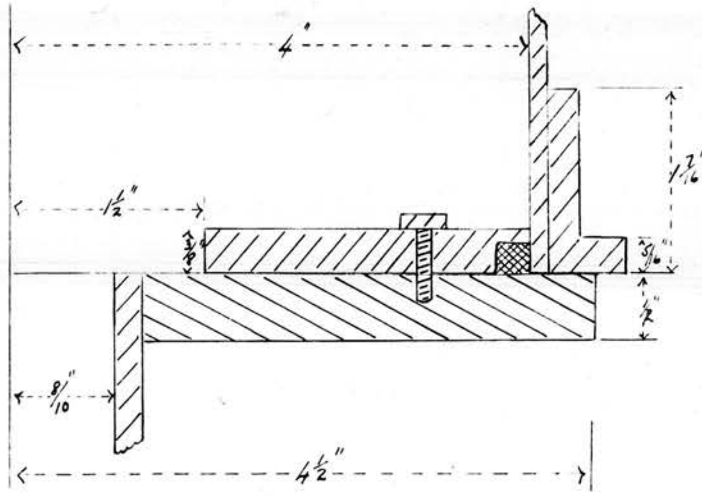


Plate II.

The Magnetic Lens Design Showing Pole Piece Controls and Reference Scales.



Top Plate Detail.



Bottom Plate Detail.

Plate III.

Top and Bottom Plate Detail.

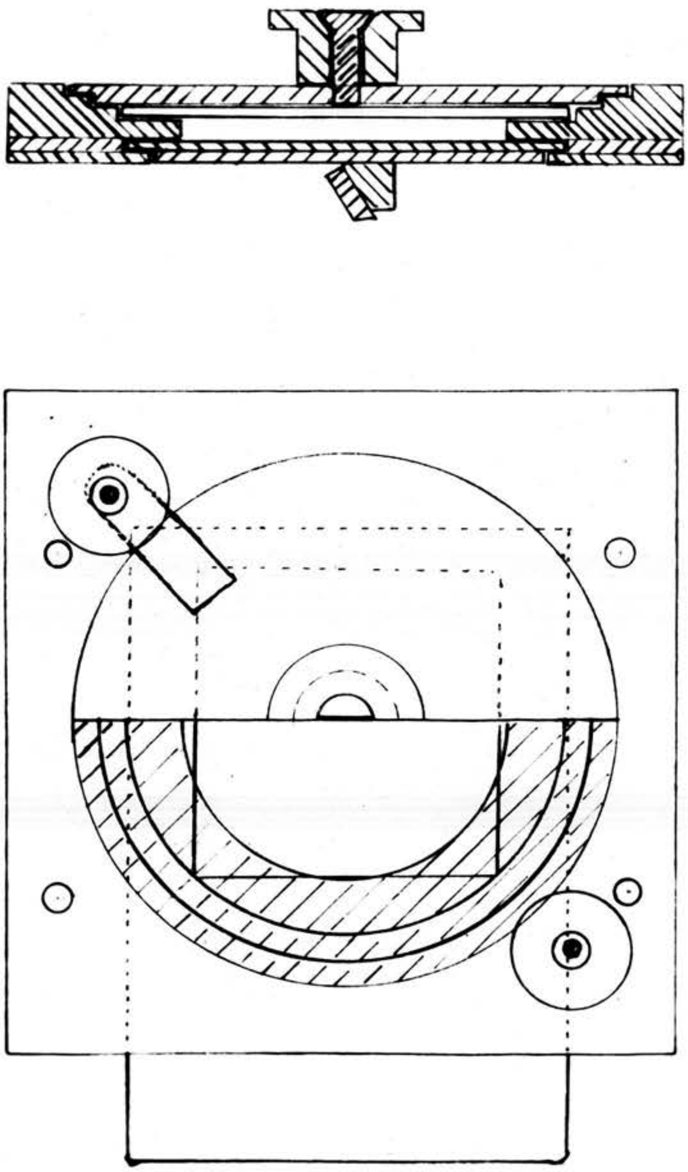


Plate IV.

The Plate Holder.

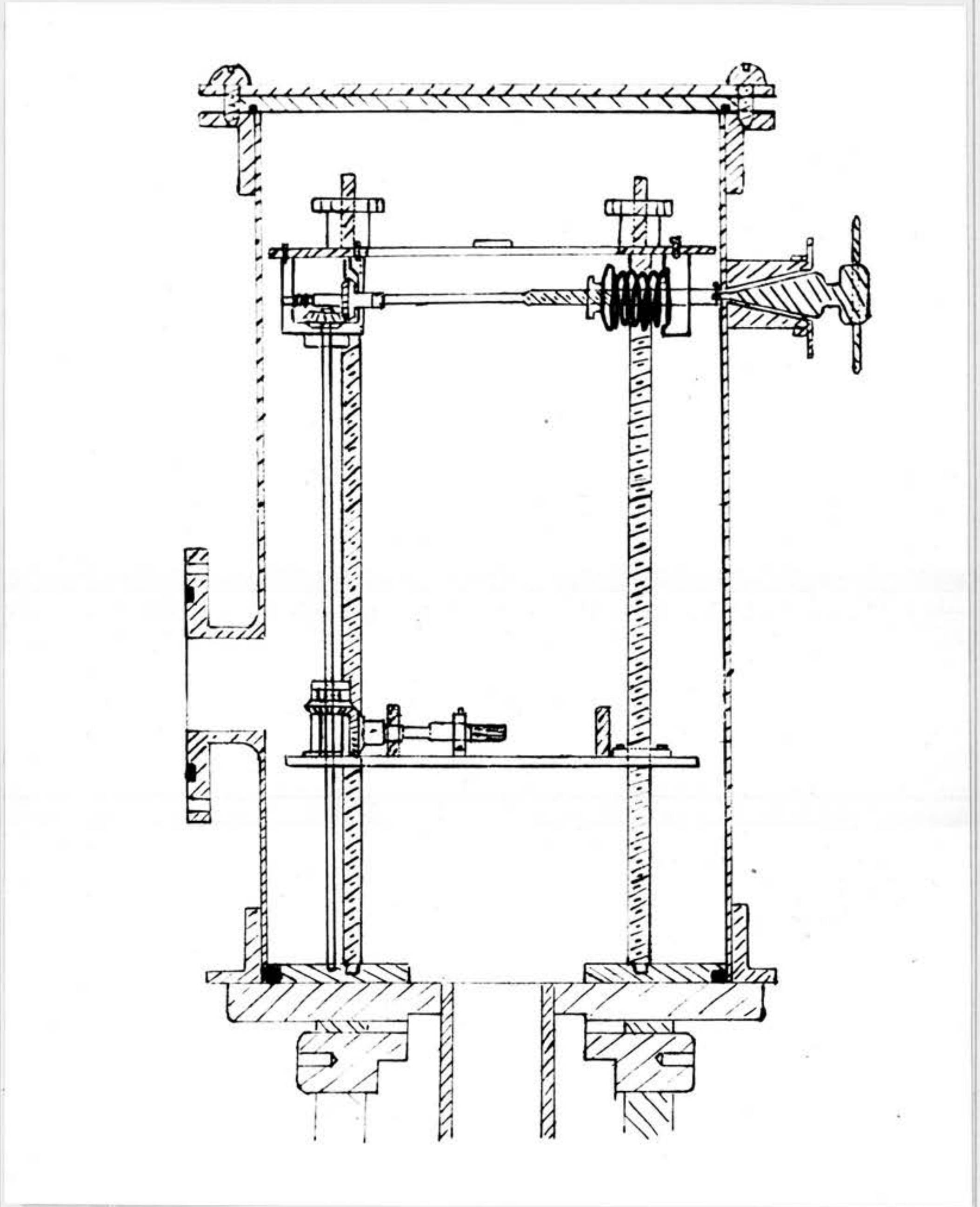
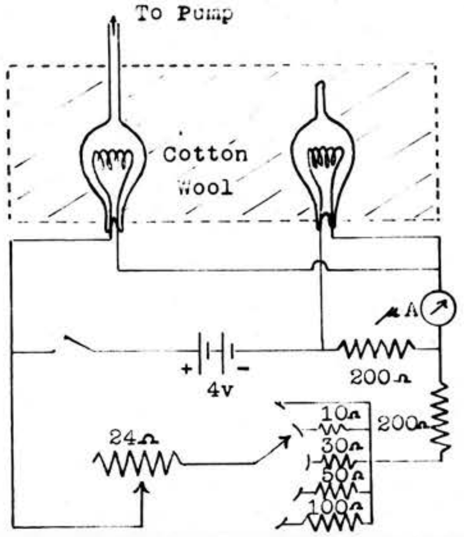
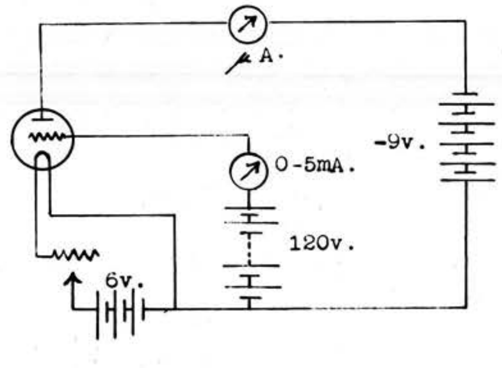


Plate V.

The Camera Interior.



The Pirani Gauge Circuit.



The Ionization Gauge Circuit.

Plate VI.

The Vacuum Gauge Circuits.

6

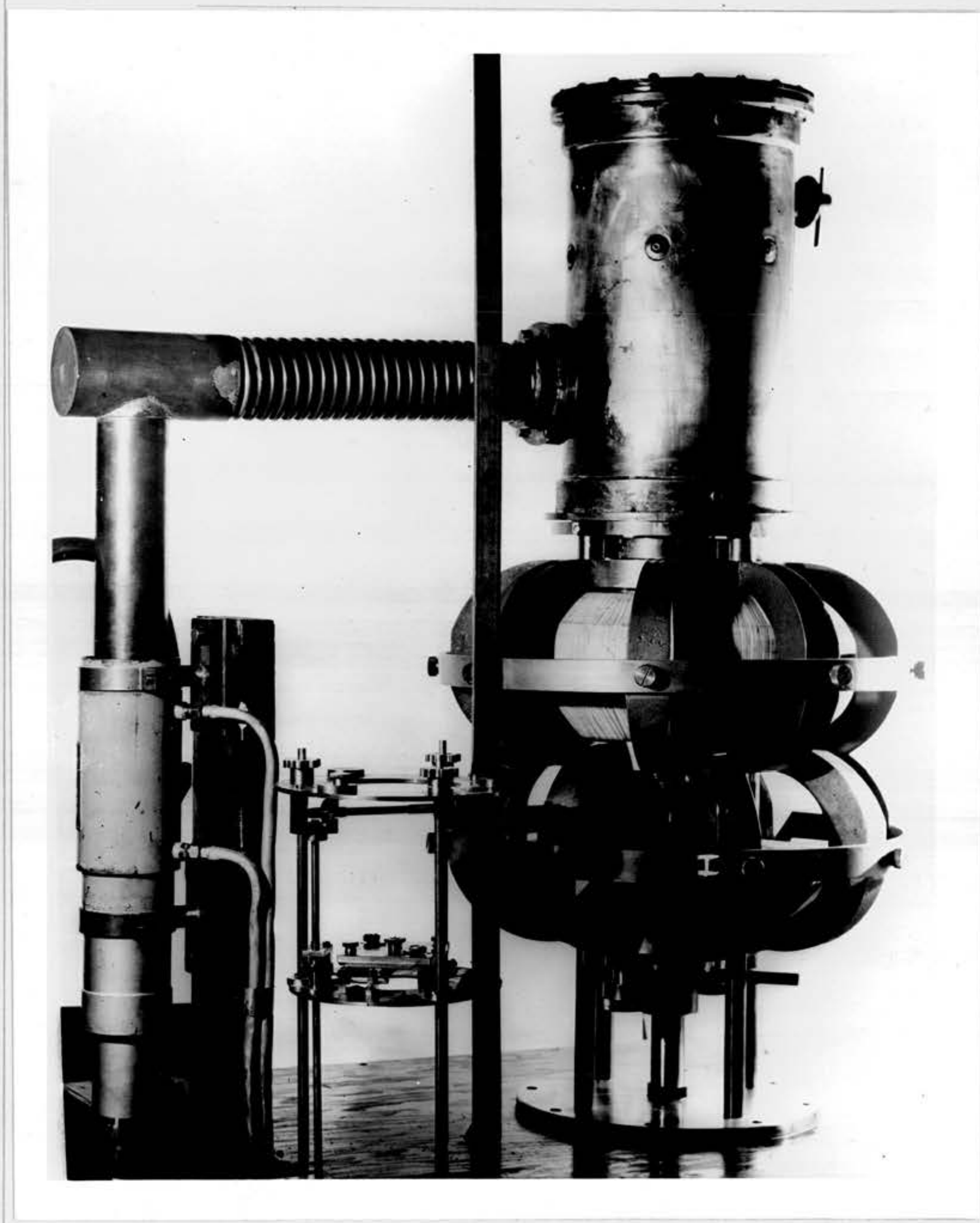


Plate VII.

The Electron Emission Microscope.

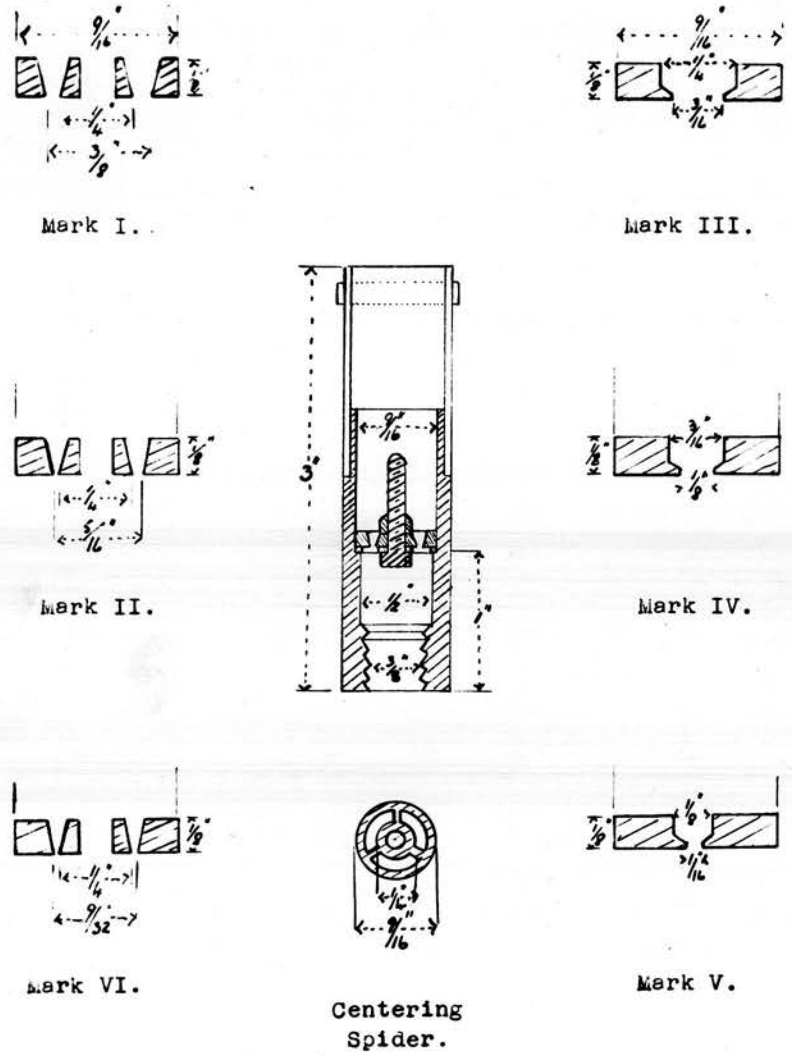


Plate VIII.

The Focusing Baffles.

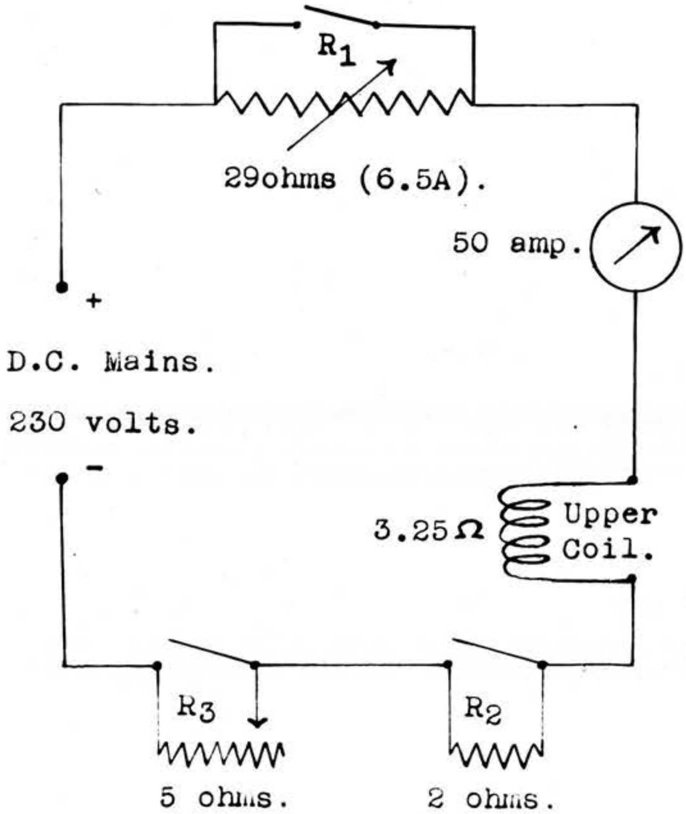


Plate IX.

The Circuit for Remagnetization of Upper Pole Piece.

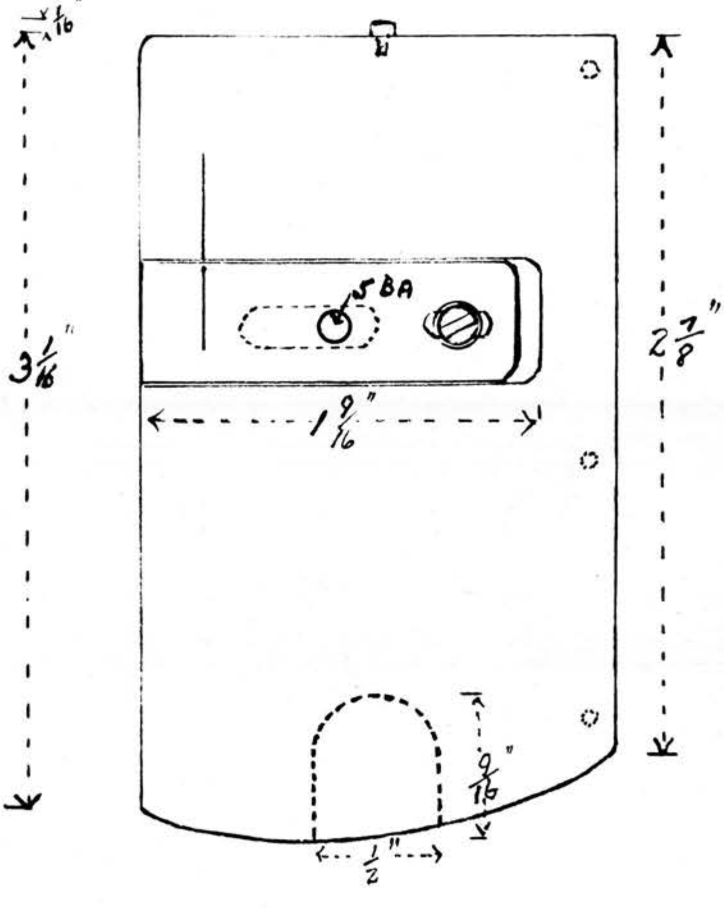


Plate X.

The Source Holder.

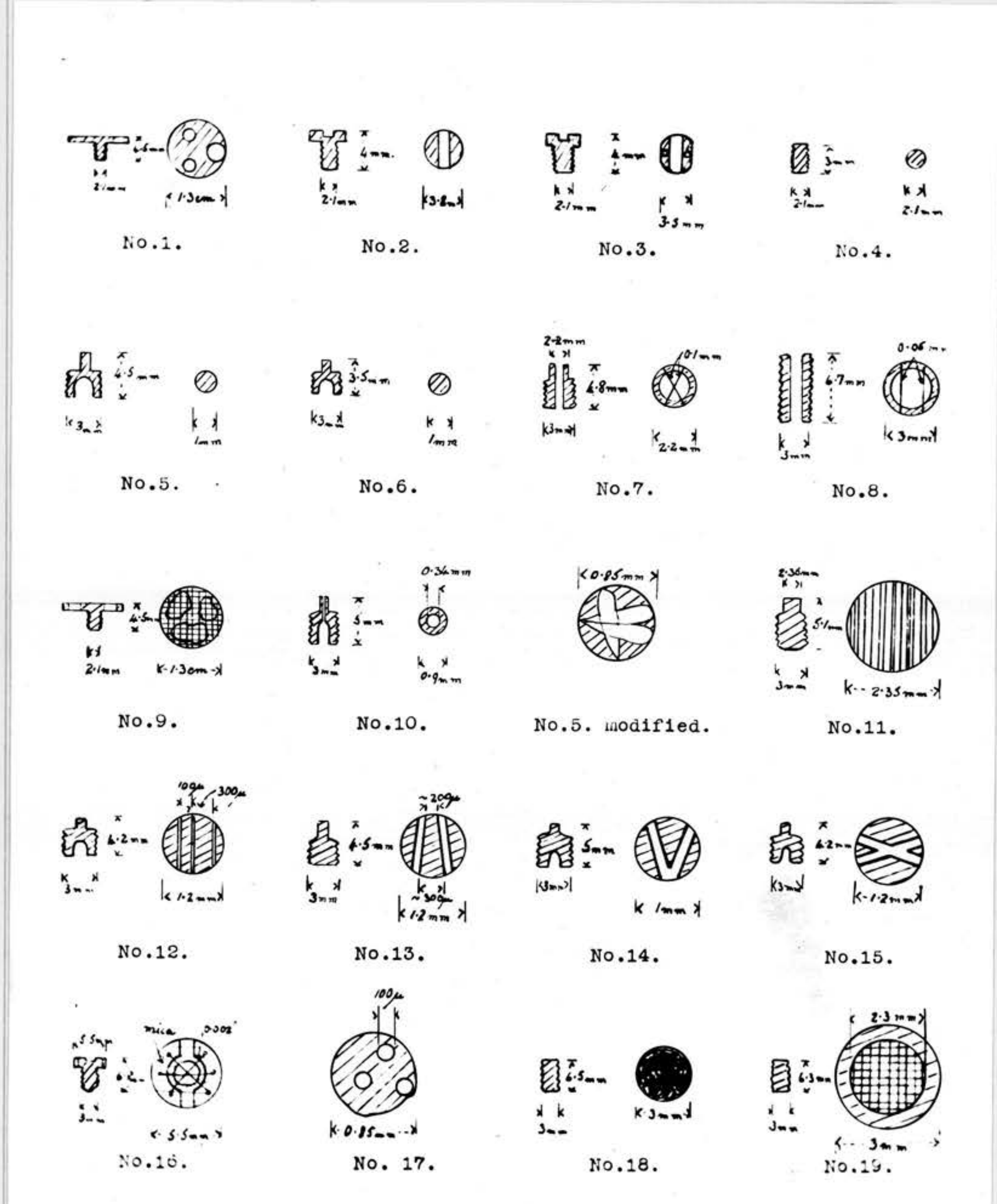
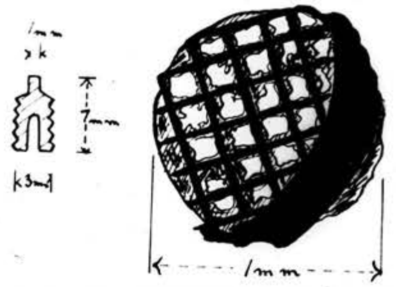


Plate XI.

The Source Buttons.



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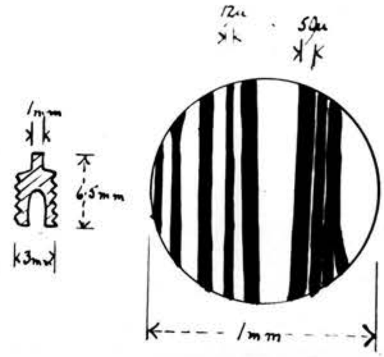

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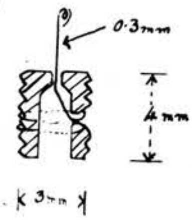
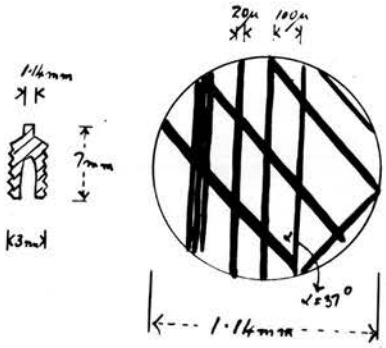


No.24.



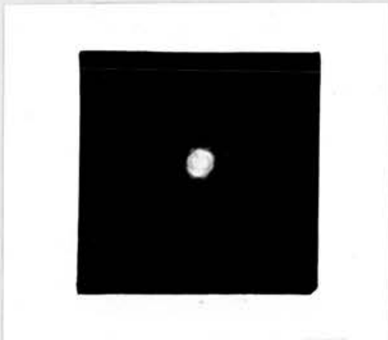
No.25.

Plate XII.

The Source Buttons (continued).

(a)

(b)



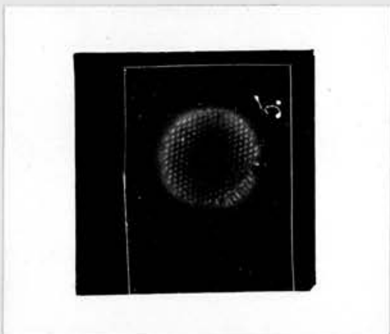
(c)

(d)

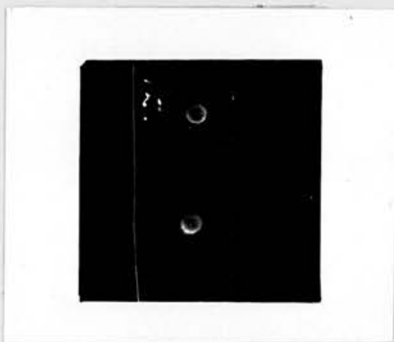
(e)

Plate XIII.

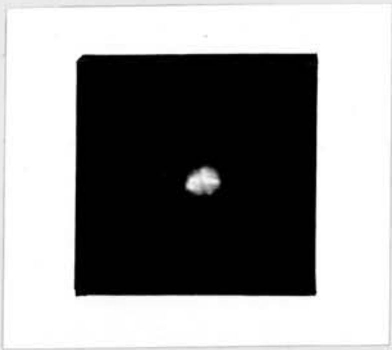
(a) Object No. 5, field width 1.7 cms., magnification 8.7, exposure 1 hr.20m., 3 hrs. 40 m. after activation, Kodirex film.
(b) Conditions as in (a) except for the following: magnification 6.6, exposure 45 m., 5 hrs. 45 m. after activation.
(c) Conditions as in (a) except for the following: magnification 3.1, exposure 30 m., 5hrs. 5 m., after activation.
(d) Object No. 6, field width 2.35 cms., magnification 8.5, exposure 2 hr. 30 m., 5 hrs. 40 m. after activation, Kodirex film.
(e) Conditions as in (d) except for the following: magnification 6.5, exposure 30 m., 40 m. after activation.



(a)



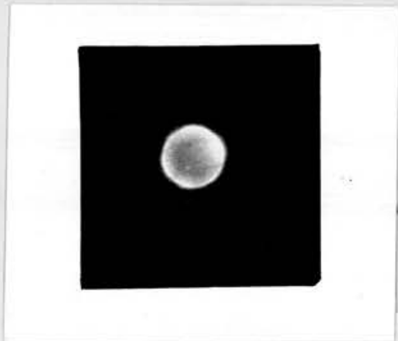
(b)



(c)

(d)

(e)



(f)

Plate XIV.

(a) Contact autoradiograph of button No. 9.

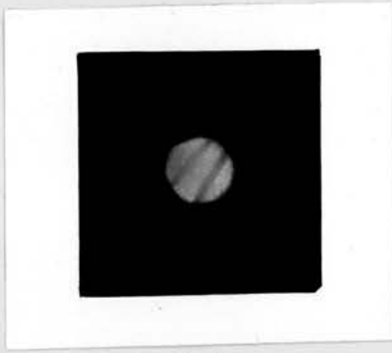
(b) Contact autoradiograph of button No. 11.

(c) Object No. 5 modified, field width 2.35 cms., magnification 5.9, exposure 40 m., 10 m. after activation, Ilfex film.

(d) Conditions as in (c) except for the following: magnification 8.5, exposure 1 hr., 4 hrs. 50 m. after activation.

(e) Object No. 11, field width 2.35 cms., magnification 3.4, exposure 5hrs. 30 m., 24 hrs. after activation, Ilford Dental film.

(f) Conditions as in (e) except that the grooves were scratched out after activation, exposure 1 hr., 15 m. after activation.



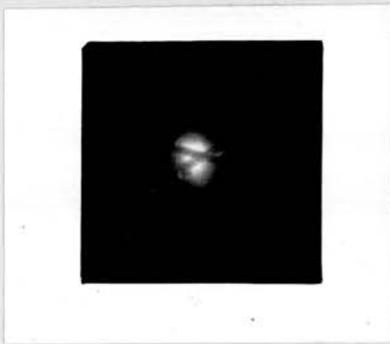
(a)

(b)

(c)

(d)

(e)



(f)

Plate XV.

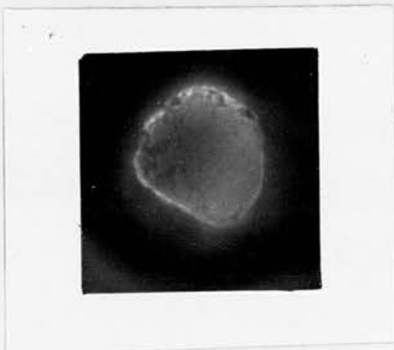
(a) Object No. 13, field width 2.35 cms., lower pole piece withdrawn, magnification 7.5, exposure 40 m. 25 m. after activation, Ilford Dental film.
(b) As in (a) except for the following: lower pole piece raised by 6 cms., magnification 8.5, exposure 1 hr. 25 m., 4 hr. 25 m. after activation.
(c) Object No. 14, field width 2.35 cms., magnification 6.5, exposure 3 hrs., 3 hrs. 40 m., after activation, Ilfex film.
(d) Object No. 15, field width 2.35 cms, magnification 7, exposure 30 m., 20 m. after activation, Ilfex.
(e) As in (d) except for the following; magnification 7.5, exposure 3 hrs., 30 m. after activation.
(f) As in (d) except for the following: field width 2.86 cms., magnification 6.5, exposure 3 hrs., 4 hr. 5 m. after activation.

(a)

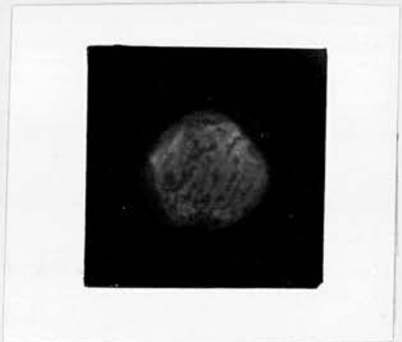
(b)

(c)

(d)



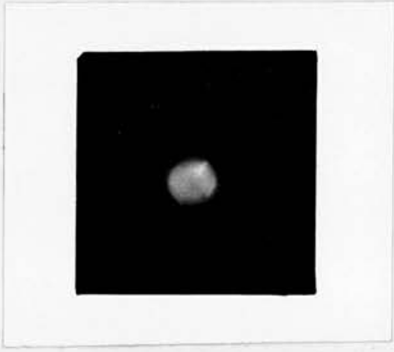
(e)



(f)

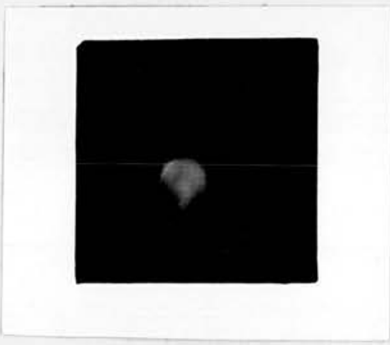
Plate XVI.

(a) Object No. 17, magnification 7, exposure 4 hrs., 20 m. after activation, Ilfex film.
(b) Contact autoradiograph of button No. 18.
(c) and (d) Contact autoradiographs of pumice stone.
(e) Object rabbit bone, 2.7 mm. diameter, magnification 7, exposure 7 hrs. 40 m., 20 m. after activation, Ilfex film.
(f) Object rabbit bone, approximately 2mm. diameter, magnification 7, exposure $22\frac{1}{2}$ hrs., 20 m. after activation, Ilfex film.

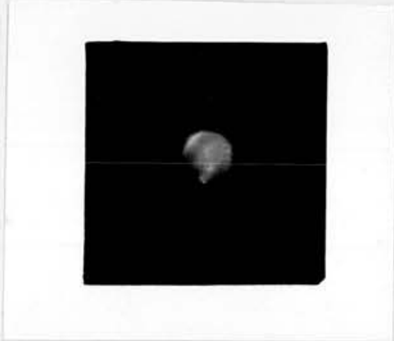


(a)

(b)

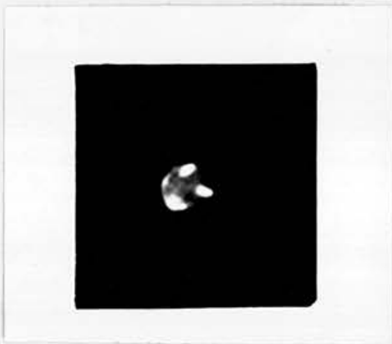


(c)

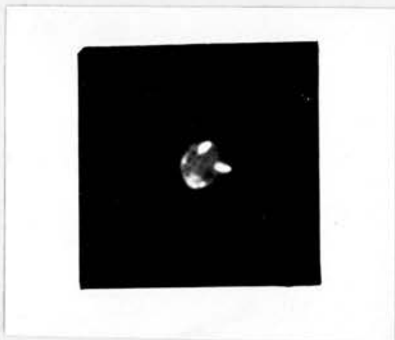


(d)

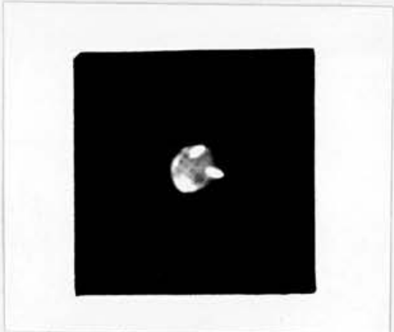
(e)



(f)



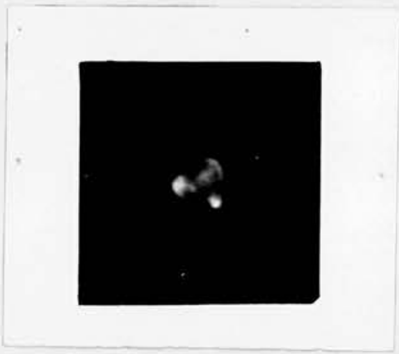
(g)



(h)

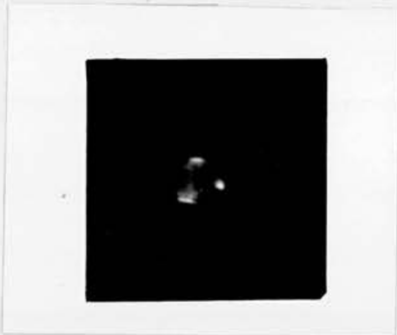
Plate XVII.

Some of the series of exposures taken with object No. 20 at various object positions.



(a)

(b)



(c)

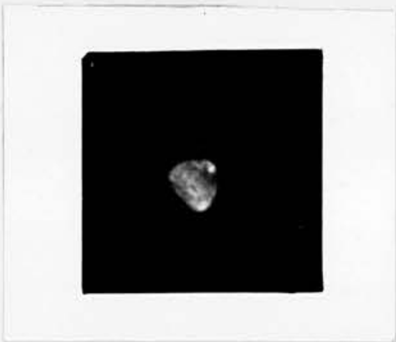
(d)

(e)

(f)

Plate XVIII.

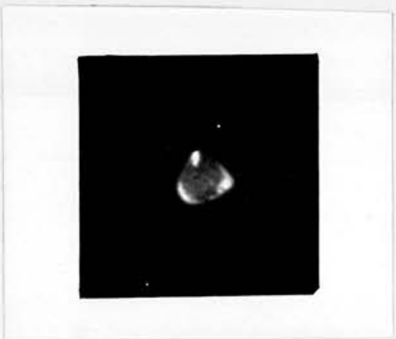
Some of the series of exposures taken with the focusing baffle in various positions from (a) 1 cm. to (f) 3 mm. above original position.



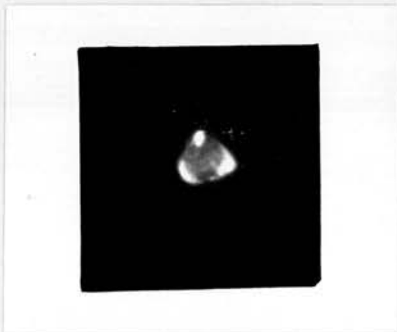
(a)

(b)

(c)



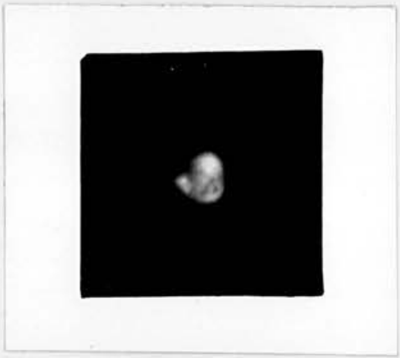
(d)



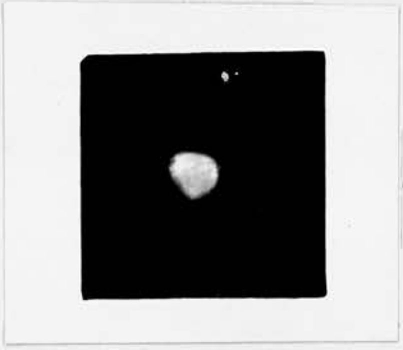
(e)

Plate XIX.

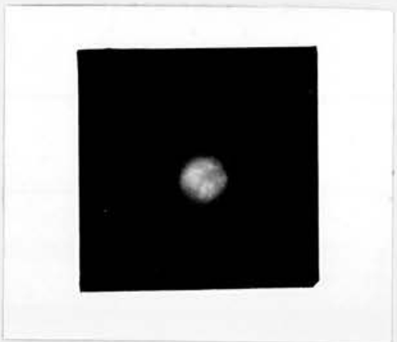
Further exposures taken with the focusing baffle in various positions from (a) 1 mm. above to (e) 7 mm. below original position.



(a)



(b)



(c)

(d)

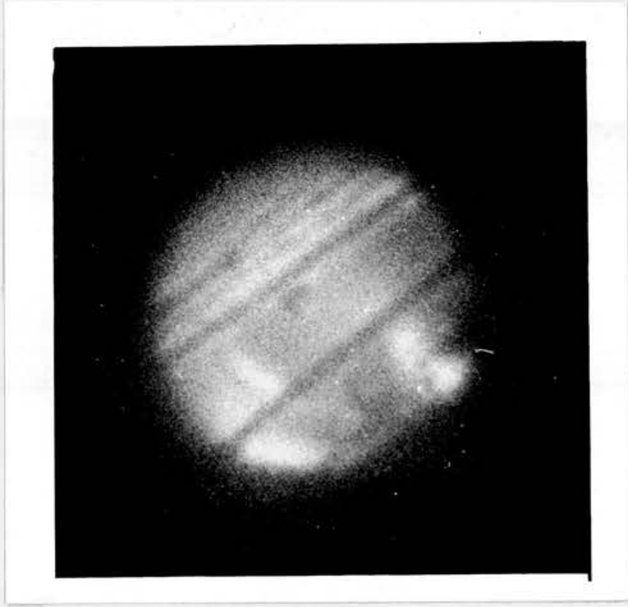
(e)

Plate XX.

Exposures with focusing baffles Mark III and V.

(a)

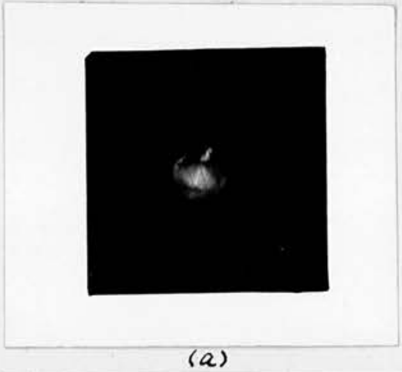
(b)



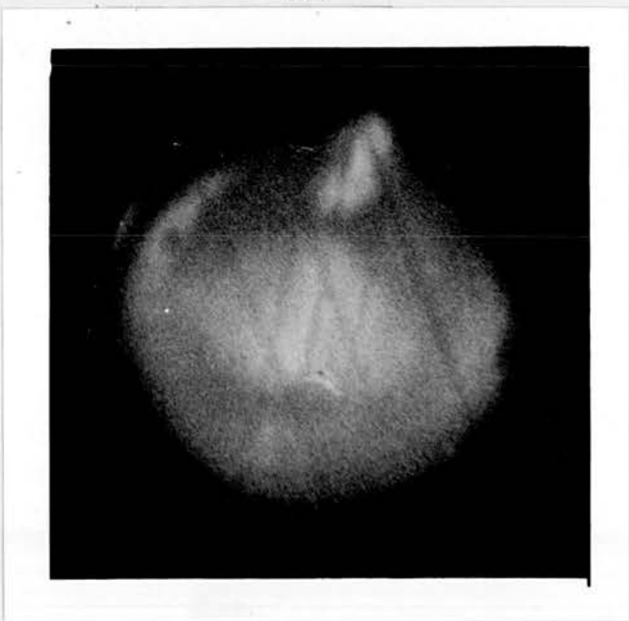
(c)

Plate XXI.

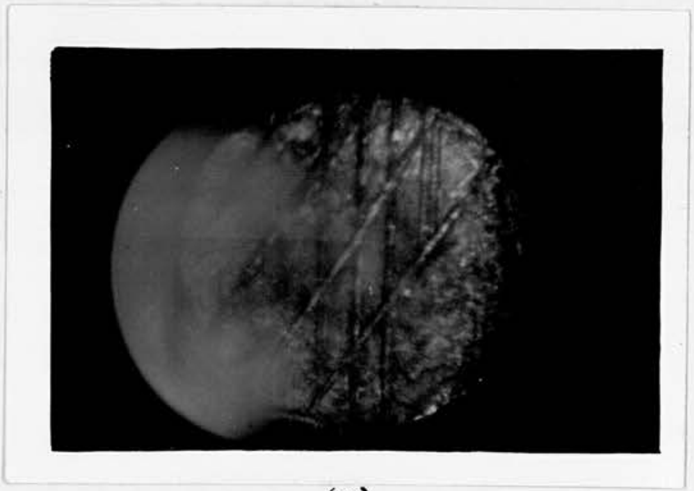
(a) Object No. 23, Mark VI baffle, magnification 7, exposure 4 hrs. 50 m., 30 m. after activation, Ilfex film.
(b) As in (a) except for the following: exposure 4 hr. 40 m., 25 m. after activation, Kodirex film.
(c) Enlargement of (a) to give a magnification of approximately 42 times.



(a)



(b)



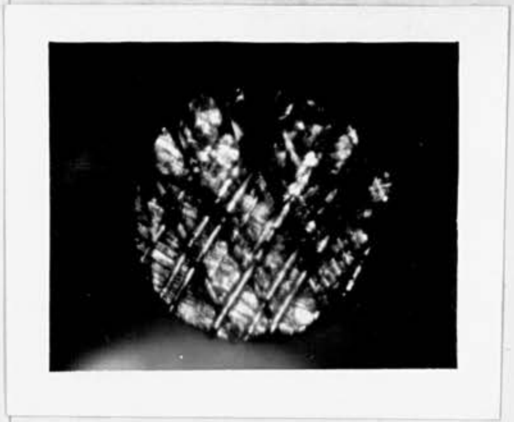
(c)

Plate XXII.

(a) Object No. 25, Mark VI baffle, magnification 7, exposure $15\frac{1}{2}$ hrs., 6 hrs. after activation, Ilfex.

(b) Enlargement of (a) to give a magnification of approximately 42 times.

(c) Projection Microscope photograph of No. 25 at a magnification of 42 times.



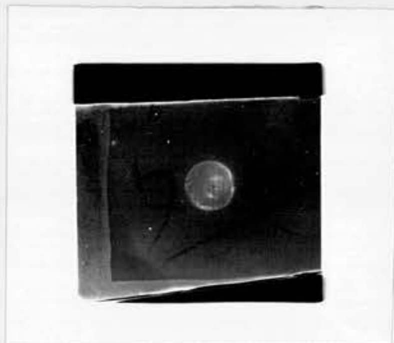
(a)

(b)

(c)

(d)

(e)



(f)

Plate XXIII.

(a) Projection Microscope photograph of button of mean diameter 0.83 mm., magnification 42 times.
(b) Electron image of button shown in (a) magnification 7, exposure 16 hrs., 6 hrs. 50 m. after activation, Ilfex film.
(c) As in (b) except exposure 2 hrs., 20 m. after activation, Kodak N.T. 2a plate.
(d) As in (c) except exposure 16 hrs., $2\frac{1}{2}$ hrs. after activation.
(e) As in (c) except exposure 23 hrs., 19 hrs. 10 m. after activation.
(f) As in (c) except exposure 47 hrs., 43 hrs. 40 m. after activation.